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Application No. S2003/0281

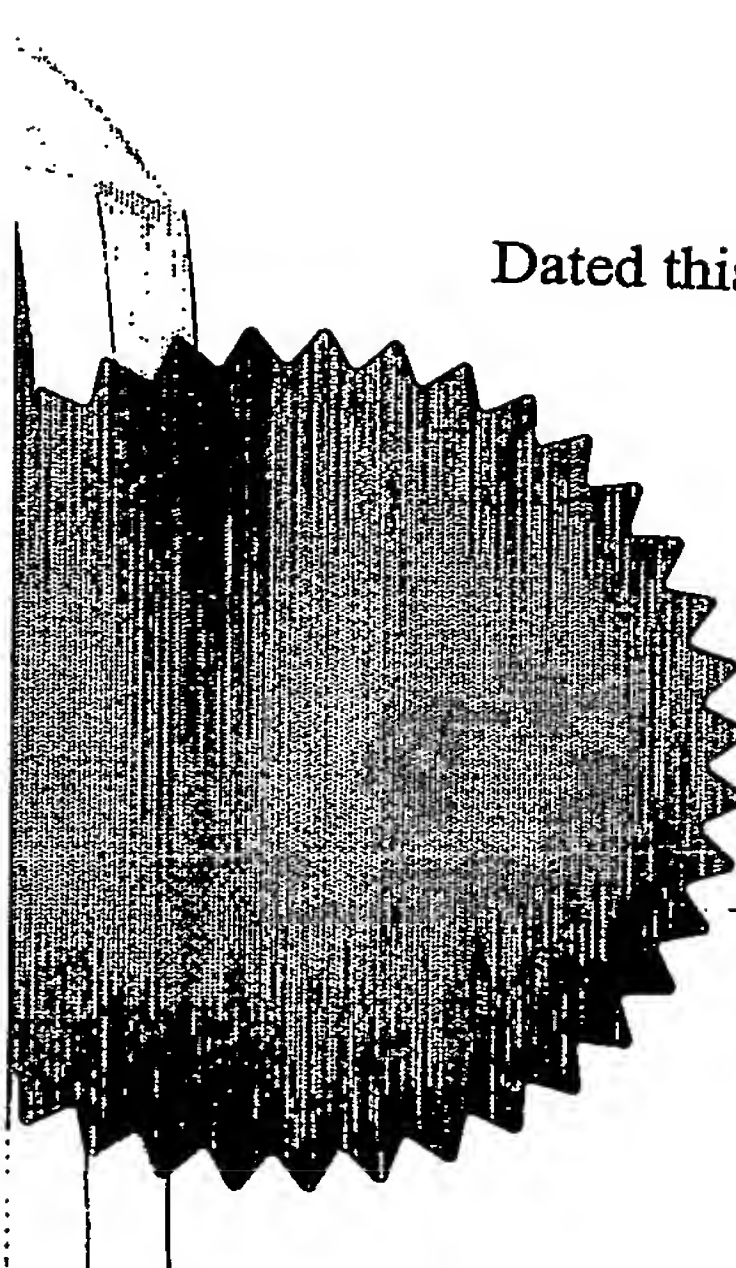
Date of Filing 14 April 2003

Applicant
INTUNE TECHNOLOGIES LIMITED, an Irish
company of 9c Beckett Way, Park West Business
Park, Nangor Road, Dublin 12, Ireland.

Dated this 22 day of April 2004.

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S 030281

Form No.1

Application No.

REQUEST FOR THE GRANT OF A PATENT

Patents Act, 1992

The Applicant(s) named herein hereby request(s)

the grant of a patent under Part II of the Act

☒ the grant of a short term patent under Part III of the Act on the basis of the information furnished hereunder

1. Applicant(s)

Name: INTUNE TECHNOLOGIES LIMITED

Address: 9c Beckett Way, Park West Business Park, Nangor Road, Dublin 12, Ireland

Description/Nationality: an Irish Company

2. Title of Invention:

METHOD AND APPARATUS FOR CONTINUOUS SWEEPING OF A TUNABLE LASER

3. Declaration of Priority on basis of previously filed application(s) for same invention (Sections 25 & 26)

Previous Filing Date

Country in or for which filed

Filing No.

4. Identification of Inventor(s):

Name(s) of person(s) believed by applicants to be the inventor(s) address:

5. Statement of right to be granted a patent (Section 17(2) (b))

Date of assignment from inventors:

6. Items accompanying this Request - tick as appropriate

(i) ☒ prescribed filing fee

(ii) ☒ specification containing a description and claims
specification containing a description only
☒ Drawings to be referred to in description or claims

(iii) ☐ An abstract

(iv) ☐ Copy of previous application(s) whose priority is claimed

Title

Method and Apparatus for continuous sweeping of a tunable laser

Field of the Invention

5 This invention relates to tunable lasers and the requirement to sweep a range of wavelengths in a continuous manner. This invention specifically relates to a method to stitch two or more continuous tuning regions of the laser together. Within the present specification
10 the term "continuous sweeping" means that there are no discernable glitches or jumps in the output frequency of the device outside of the smooth sweep across the wavelength range of interest.

Background to the Invention

15

Multi section laser diodes are well known in the art and can be switched between different wavelengths. Typically, the diode is calibrated at manufacture to determine the correct controls that should be applied so as to effect
20 the desired output frequencies from the laser.

One of the first known multi-section laser diodes is a three-section tuneable distributed Bragg reflector (DBR) laser. Other types of multi-section diode lasers are the
25 sampled grating DBR (SG-DBR), the superstructure sampled DBR (SSG-DBR) and the grating assisted coupler with rear sampled or superstructure grating reflector (GCSR). There are also other laser types such as the External Cavity Laser (ECL) and gas lasers. A review of such lasers is
30 given in Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Arctect House, 1998 and "Widely Tuneable Semiconductor Lasers" ECOC'00. Beck, Mason.

Figure 1 is a schematic drawing of a DBR 10. The laser
35 comprises of a Bragg reflector sections 2 with a gain or

active section 6 and phase section 4. An anti-reflection coating 9 is sometimes provided on the front and/or rear facets of the chip to avoid facet modes. The Bragg reflector takes the form of Bragg gratings 5. The pitch of the gratings of the Bragg reflector varies slightly to provide a Bragg mode which moves in frequency through varying the current supplied to this sections. The optical path length of the cavity can also be tuned with the phase section, for example by refractive index changes induced by varying the carrier density in this section. A more detailed description of the DBR and other tuneable multi-section diode lasers can be found elsewhere Jens Buus, Markus Christian Amann, "Tuneable Laser Diodes" Artech House, 1998.

As detailed above such tunable semiconductor lasers contain sections where current is injected to control the output frequency, mode purity and power characteristics of the device. Various applications in

telecommunications/sensor fields require the laser to sweep across a particular wavelength range in as continuous a manner as possible. Moreover many applications require that the range in wavelength that is to be swept to be quite large, up to 80nm and higher.

However, certain types of tunable lasers have only a set of narrow ranges of wavelengths over which they can be continuously tuned. These individual continuously tuneable regions when put end to end will cover the full sweep range of interest with some overlap.

It is desirable therefore to have a scheme by which each of these continuous regions can be seamlessly stitched together to give the appearance of continuous tuning.

Object of the invention

The object of the present invention is to provide a method for stitching together continuous regions of a multi-section tunable laser in an efficient and accurate
5 manner.

Summary of the Invention

Accordingly the present invention provides a method
10 adapted to identify for a predetermined wavelength the end of a first continuously tunable region within the range of operation of the laser and thereafter to once again identify this same wavelength at the beginning of a second continuously tunable region with high accuracy.

15 Desirably the first and second continuously tunable regions are adjacent or overlap with one another. A control signal can then be provided to highlight the times when continuous tuning operation is being
20 performed. By limiting a suitable receiver to only make measurements when the control signal is asserted, the method of the present invention provides for a high level of confidence in the continuous tuning behaviour in the measurements. The methodology and technique is generic to
25 all types of laser devices and therefore can be applied to several different types of tunable laser such as ECL, DBR, SG-DBR, GCSR etc.

Desirably, once the first and second continuously tunable
30 regions are identified, a method of stitching them together so as to form a usable tuning data set may be provided.

According to first embodiment of the present invention a
35 method of providing a set of continuous tuning regions

from a discontinuously tuned laser is provided, the method comprising the steps of:

providing a wavelength reference having at least first and second resonance peaks,

5 sweeping the laser across a pre-determined wavelength range of the wavelength reference, and

defining, within the laser sweep, one or more regions of continuous tuning operation of the laser, each of the regions corresponding to a response of the laser
10 between adjacent resonance peaks of the wavelength reference.

Desirably, the one or more regions of continuous tuning operation are adjacent to one another. Alternatively, the
15 one or more regions of continuous tuning operation are displaced from one another across the pre-determined wavelength range. In such an alternative the regions may be chosen randomly within the pre-determined wavelength range.

20

The method may further comprise the step of:

stitching two or more regions to one another so as to form a usable tuning data set.

25 Such stitching the two or more regions to one another is desirably effected by:

- a. creating a lookup table of regions that have continuous tuning over a first frequency region with a frequency overlap on either side with the
30 previous and next continuous tuning regions,
- b. asserting a control signal to denote a continuous region when the first resonance peak is detected,
- c. de-asserting the control signal and jumping to
the next continuous tuning region when the next
35 resonance peak is found within this continuous tuning region, and

- d. repeating the above steps (b-c) until a sufficient range of wavelength has been swept.

5 The regions of continuing tuning operation of the laser are desirably defined by:

calibrating the laser so as to provide a range of currents with no mode jumps,
selecting continuous regions with a first frequency overlap that have a resonance peak in the
10 wavelength response from their beginnings and ends, and
setting the currents whilst sweeping through those wavelengths so as to provide a smoothly
transitioning wavelength sweep.

15

The step of setting the currents is typically provided by one or more of the following:

filtering,
shaping.

20

In preferred embodiments the method may include the additional step of assigning a frequency (F_{meas}) or wavelength (λ_{meas}) value to discrete points within the continuous region of operation of the laser device, the
25 value being assigned by:

measuring the time from the resonance peak at the beginning of the sweep to the measurement instant (T_{meas}),
measuring the time required to sweep between
30 adjacent resonance peaks (T_{segment}), and
calculating the value by extracting a value for T_{meas} from T_{segment}

For application of a frequency value and using an etalon
35 as a wavelength reference the method typically includes

the step of calculating the frequency using the equation:

$$F_{\text{meas}} = FSR_{\text{Etalon}} * \frac{T_{\text{meas}}}{T_{\text{segment}}} + F_{\text{SegmentStart}}$$

where FSR_{Etalon} is the free spectral range of the reference etalon and $F_{\text{SegmentStart}}$ is the absolute frequency of the first resonant etalon peak in the segment.

The laser device may be used as a reference source for a second device. Such an application may use the regions of continuous tuning operation to define the spectral characteristics of a second laser device, or to provide an optical spectrum analyser.

The wavelength reference is desirably provided by one or more of the following:

- a fabry perot etalon,
- a gas cell,
- fabry bragg grating,
- notch filter,
- a reflective fabry perot etalon, and
- optical filter.

Any portion of the resonance peak may be used to determine the location of the resonance peak.

The invention additionally provides an optical arrangement adapted to provide a set of continuous tuning regions from a discontinuously tuned laser, the arrangement comprising:

- a wavelength reference having at least first and second resonance peaks associated therewith,
- a tunable laser,
- means for sweeping the laser across a pre-determined wavelength range of the wavelength reference, and

means for defining, within the laser sweep, one or more regions of continuous tuning operation of the laser, each of the regions corresponding to a response of the laser between adjacent resonance peaks of the wavelength
5 reference.

These and other features of the present invention will be better understood with reference to the following
10 drawings.

Brief Description of the drawings

Figure 1 shows a schematic of a Distributed Bragg
15 Reflector Laser diode.

Figure 2 shows a schematic of an embodiment of the system in a typical application.

Figure 3 shows how a continuous sweep may be obtained from a mode plane.

20 Figure 4 is an example of the output of the high finesse etalon in one of the continuous sweep regions of the laser.

Figure 5 is an example of the spectral characteristics of a fabry-perot filter as used in the methodology of the
25 present invention.

Figure 6 is a plot of frequency vs. time for a system utilising the method of the present invention.

Figure 7 is a schematic of a second application of the methodology of the present invention.

30 Detailed Description of the Drawings

The invention will now be described with reference to exemplary embodiments thereof and it will be appreciated that it is not intended to limit the application or
35 methodology to any specific example. The techniques used by the method of the present invention are specifically

provided to enable the formation of a continuous sweep from a discontinuously tuned laser. A continuous sweep is taken to be one which has no discernibly or substantial glitches in frequency along its length, only a smooth transition across the full wavelength range.

The methodology of the present invention will now be described with reference to a three section DBR device, and it will be appreciated from a person skilled in the art that this is only exemplary of the type of device that may be used with the method of the present invention. It will be further appreciated that the technique and methodology herein described is a generic technique being applicable to all narrow and widely tunable lasers such as the SG-DBR, SSG-DBR, DBR and GCSR types.

Figure 2 shows a typical embodiment of the system for a typical application, the system shown enabling the spectral characterisation of the device under test. A tunable laser and control electronics 300 provide the optical output where the output wavelength and power of the laser are controlled by the electronics. The optical power from the laser is passed through a 3-way splitter 310. Part of the light goes to a wavelength reference 340, a direct power measurement 350 and to a device under test (DUT) 320. Three receivers are provided (370) to monitor the wavelength reference power, direct power and the DUT power. These are typically measured with photodetectors 331, a, b, c and a trans-impedance amplifier 332 a, b, c and the voltages are passed back to the laser and control electronics 300. Connector blocks or interface units 390 are also provided to enable the removable coupling of the DUT, one unit coupling it to the 3-way splitter and the second to the corresponding receiver 360 for the DUT. In operation such an embodiment

of the invention provides for the analysis of the spectrum of the device under test by comparison with the control laser/wavelength reference combination.

5 This application to an accurate wavelength spectral characterisation is only one exemplary embodiment of the invention. Other embodiments may include the use of the methodology within an interrogators or optical spectrum analyser.

10

To achieve the high accuracies required a wavelength reference is required that can be used in conjunction with the laser. In this exemplary technique, a Fabry Perot etalon is used but it will be appreciated that
15 other references can be used which provide a similar characteristic. The Fabry Perot (FP) filter that is used desirably has a high Finesse (>30). A high finesse filter will be less dependent on output power variations of the tunable laser. The spectral characteristics of such a
20 filter is shown in Figure 4. It will be apparent, as shown in Figure 5, that such a filter has at least two resonance peaks, each being associated with a high level of transmissivity at specific frequencies. Between these peaks the filter exhibits low levels of transmissivity.

25 This means that there is a large extinction ratio between the resonance peaks and away from the resonance peak. This also means that the spectral width of the filter is small ($<5\text{pm}$). As the laser sweeps across the wavelength ranges, when the wavelength coincides with a resonance
30 peak a response is obtained on a receiving photodiode. As the Free Spectral Range (FSR and the start frequency of the FP filter is well know and an approximate frequency of the laser is known (from, for example, an initial calibration of the laser) when the laser wavelength is at
35 a resonance of the FP filter the wavelength of the laser can be determined very accurately (to much better than

0.1pm resolutions). This enables high accuracy of the laser source to be determined at the wavelength reference peaks as the wavelength at each peak is known accurately. and the laser is calibrated so that in-between each
5 resonance the wavelength tuning is linear in time, therefore the wavelength at any point between two such resonance's can be referenced from the time taken for the laser from the first resonance to the second resonance, i.e.

10

λ_1 = Wavelength of the first resonance

$\lambda_1 + \text{FSR}$ = wavelength of the second resonance

T = time to sweep from λ_1 to the second resonance peak

K = time to reach a wavelength between the two resonance's

15 λ = wavelength at time K

Therefore

$$\lambda = K/T * \text{FSR} + \lambda_1$$

20

Another example of a suitable wavelength reference would be a gas cell. It will be understood that a gas cell will provide a multitude of reference peaks to reference the tunable laser while sweeping, and while these peaks are not typically displaced regularly from one another, the use of such a cell is advantageous in that it is less
25 susceptible to pressure or temperature effects and can therefore serve as a more accurate reference than for example the fabry-perot etalon. In a further example an etalon could be referenced to a gas cell, so as to provide an absolute reference and then the substantially
30 regular intervals between the resonance peaks of the fabry-perot could be used in combination with the tunable laser in the method of the invention.

35

As can be seen from Figure 3 a continuous tuning region is obtained by finding a line which crosses no mode

boundaries 210. This is shown as a black line 200 in a phase, bragg plane, where the degree of shading denotes the output wavelength of the laser. By choosing a region to sweep the currents that do not cross a mode jump of the laser continuous tuning is achieved. This can be accomplished in a number of ways as reported in "Complete Wavelength Control of a GCSR Laser over EDFA Band" IEEE LEOS'99, San Francisco, Nov'99, T. Farrell et al. This results in a set of continuous tuning regions and a subset of these is taken which cover the wavelength range of interest.

Figure 4 shows the current on the phase section of the laser vs. the output frequency of the laser. It will be appreciated that similar plots may be obtained for the other sections of the laser which must be controlled in a similar manner to achieve the continuous tuning. Specifically, a similar control current function is required for the Bragg section in the case of a 3 section DBR laser, and of the front and back reflector sections of the SG-DBR laser. If there is a requirement to keep the output power of the laser constant during the sweep the gain section can also be controlled to compensate. Use of a Digital to Analog Converter (DAC) which will step the currents at the required resolution, can be used to implement this, as will be appreciated by those skilled in the art. Also an electronic filter can be used to smooth the currents to achieve smooth continuous tuning of the laser source.

Once a series of these continuous sweeps has been identified, a set of continuous regions can be selected each of which overlap by a predetermined frequency, typically 10 GHz, and each of which starts and end 10 GHz from one of the peaks of the high finesse etalon. Each continuous tuning range of the laser will sweep the

wavelength of the laser across two different peaks, so that all the continuous tuning ranges cover all the gaps between reference peaks in the wavelength range of interest. The laser may then be swept through each of these continuous regions. In operation, the wavelength reference of the filter is used to identify the regions of the sweep that are used. This is performed by using a control signal which is asserted when the sweep hits a first wavelength reference and de-asserted when the sweep hits a second reference. A control signal can be generated by use of a threshold operation on the response of the wavelength reference. When the light level is above a threshold value, this signifies that the wavelength of the laser is at the wavelength reference wavelength of that peak. This can be implemented with the use of a comparator and some simple logic elements. A reference is identified when the optical power received through the reference is above a threshold. This is explained in more detail in the following sections.

When sweeping the laser across one continuous tuning region the sweep will cross two wavelength reference peaks, equivalent to the two peaks of the etalon. Upon the wavelength of the laser hitting the first wavelength reference peak the control signal is asserted. This means that the laser is now sweeping linearly across a wavelength range between two reference wavelengths. Upon hitting the second etalon peak in this continuous sweep it de-asserts the control signal associated with the continuous regions of the sweep and starts sweeping along the beginning of the overlapping region of the next continuous region. Then the next continuous wavelength tuning region is used. During this sweep it once again detects the peak of the wavelength reference it will know it is at exactly the same frequency as the end of the last sweep and can reassert the control signal thereby

providing seamless continuity in the tuning with no gaps or overlaps in wavelength in the measurements.

Figure 6 shows a plot of Frequency vs. Time for the system with measurements only being taken when the control signal is asserted. The gaps in the response allow for the sweeping of the laser in regions where the control signal is not asserted and therefore not used. It will be appreciated that although there are breaks in between each of the sets of continuous regions that these breaks represent time delays and that the end point of one set and the start point of a second set are at the same wavelength (as could be seen from the intercept of both points against the Y-axis, line 430). It will be also appreciated that time can be allowed for the laser to reach thermal equilibrium between each continuously tunable region.

As such it will be appreciated that Figure 6 represents a reference spectrum for the tunable laser 300, which can then be used for examination of the characteristics of the DUT 325. A linear continuous curve may be formed from extrapolation of the data provided in Figure 6.

The wavelength reference used allows exact wavelength calibration of the sweep. This is significant as the output wavelength of the laser can change due to degradation, ambient temperature etc. An important property of this system is that as the laser degrades etc. the absolute wavelength of the laser can vary but the linearity of the sweep is constant. The rate of change of wavelength of the sweep can also vary but by the novel implementation defined in this patent the calculation of the wavelength at any time is not affected.

A second embodiment can be described once again with reference to a three section DBR device.

Again as can be seen from Figure 3 a continuous tuning region is obtained by finding a line that crosses no mode boundaries. This can be accomplished in a number of ways such as in "Complete Wavelength Control of a GCSR Laser over EDFA Band" IEEE LEOS'99, San Francisco, Nov'99, T. Farrell et al. The simplest is to locate each of the mode boundaries using some appropriate type of filter and compute the equation of the line between them.

Once a series of these continuous sweeps has been identified, a set of continuous regions can be selected each of which overlap by a predetermined frequency such as 10 GHz and each of which starts and ends 10 GHz from one of the peaks of the high finesse etalon. The laser then sweeps through each of these continuous regions. Upon hitting the second etalon peak in a particular continuous sweep it de-asserts the control signal associated with the continuous regions of the sweep and starts sweeping along the beginning of the overlapping region of the next continuous region. When during this sweep it once again detects the peak of the etalon it will know it is at exactly the same frequency and can reassert the control signal thereby providing seamless continuity in the tuning with no gaps or overlaps in wavelength in the measurements.

The accuracy and performance of the tunable laser is dependent on the accuracy of the calibration. By calibrating the laser to high accuracy and achieving a linear wavelength sweep with respect to time this novel technique can deliver high speed and high accuracy not available with existing techniques technology.

If a sweeper with sub 0.1 pm accuracy is required over a typical 40nm sweep range this results in 40,000 points that have to be set on the laser. For each of these points multiple currents have to be controlled to ensure linear tuning, good SMSR, line width and constant output power. This can result in a large amount of data, i.e. for a SG-DBR laser where 4 laser sections are controlled (Front reflector, Back reflector, Phase and Gain or SOA) the number of bytes of data in a lookup table is 40,000 different set points multiplied by 4 controlled sections by 2 bytes to store the set value = $40,000 \times 4 \times 2 = 320$ Kbytes. While this is straightforward for a PC in an actual instrument this will rapidly become the bottleneck and the sweep speed will suffer. For example for a sweep speed of 100ms, the data needs to be retrieved at 3.2Mbytes/sec processed and set to the laser. The methodology of the present invention may be extended to provide a method of approximating the tuning of each section that allows for data minimisation and speed of sweep.

Figure 4 shows the characteristic tuning of a segment of the laser. It will be noted that the other sections of the laser must be controlled to achieve this type of tuning. To get a good approximation of this curve a complex equation is required to fit, an example of which will be given as below.

An approximation that works well over most of the tuning rate is

$Y = a + b / (c - x)$ where y is the output frequency of the laser and x is the phase current.

As this function requires a divide to calculate this takes significant time and reduces the overall speed of sweep possible. Use of a polynomial approximation can

provide sufficient accuracy with enough coefficients to a given or required wavelength accuracy. Also reducing the segment size can greatly reduce the error of a low order polynomial fit. The advantage of using a polynomial fit is that this can be implemented by using a set of difference equations and result in a set of additions to be performed rather than time consuming multiplies or divides.

10 By using a polynomial which can be calculated as a set of additions this means that the speed of the calculations can be performed quickly and not effect the speed of the sweep. This means that the sweep speed can be limited by the physical properties of the laser instead of the supporting electronics.

It will be appreciated that the present invention provides a method for establishing a continuous tuning set from a discontinuous laser. Such a method of operating a tunable laser, as provided by the present invention provides a high accuracy sweeping tunable source by means of a wavelength reference. The method desirably provides for a calibration of a tunable laser in a manner that provides for continuously tunable segments between each known wavelength from the wavelength reference. As will be understood from the above mentioned exemplary embodiment, any gaps between known wavelengths of the wavelength reference are traversed by a single segment, and desirably each of the continuously tunable segments overlaps with the adjacent segments.

By calibrating the tunable laser in a manner wherein the wavelength tuning is constant with time while in operation, the wavelength of the laser at any time can be

calculated from the wavelength references at the time for the laser to tune between them

In a further embodiment, as shown in Figure 7, the DUT
5 can be an optical source and the system can be configured to measure the wavelength of the optical source as a wavelength meter, or perform as an optical spectrum analyser. This involves a heterodyne detection method 371 where the optical light from the tunable laser and the
10 optical device under test are mixed (in coupler 311) and a beat signal generated. This beat signal is at a frequency of the difference between the two optical signals. By low pass filtering the photodiode detector a beat will only be present on the receiver when the
15 frequency difference between the two optical signals is less than the bandwidth of the low pass filter. The heterodyne receiver performs the following actions

1. AC couple the photodiode response

2. Low Pass the photodiode response

3. Rectify the low passed output

4. Low pass the rectified output or integrate and dump.

With use of the correct bandwidths when the optical wavelength of the DUT and the tunable laser are within the required wavelength of each other a signal is
25 received on the heterodyne receiver. As the wavelength of the tunable laser is known the wavelength of the DUT can be measured.

It will be appreciated that the present invention
30 provides a method that enables the use of resonance peaks in a wavelength reference to define regions of continuous operation of a discontinuous laser device. By subdividing the operating region of the laser device into segments or
regions of continuous operation the present invention
35 provides for continuous operating regions in an extended sweep of the laser device. This has application in a

number of different fields for example as an optical spectrum analyser or the like.

Claims

1. A method of providing a set of continuous tuning
5 regions from a discontinuously tuned laser, the method
comprising the steps of:

providing a wavelength reference having at least
first and second resonance peaks,

10 sweeping the laser across a pre-determined
wavelength range of the wavelength reference, and
defining, within the laser sweep, one or more
regions of continuous tuning operation of the laser, each
of the regions corresponding to a response of the laser
between adjacent resonance peaks of the wavelength
15 reference.

2. The method as claimed in claim 1 wherein the one or
more regions of continuous tuning operation are adjacent
to one another.

20 3. The method as claimed in claim 1 wherein the one or
more regions of continuous tuning operation are displaced
from one another across the pre-determined wavelength
range.

25 4. The method as claimed in claim 1 further comprising
the step of:

stitching two or more regions to one another so as
to form a usable tuning data set.

30 5. The method as claimed in claim 4 wherein the step of
stitching the two or more regions to one another is
effected by:

35 a. creating a lookup table of regions that have
continuous tuning over a first frequency region

- with a frequency overlap on either side with the previous and next continuous tuning regions,
- b. asserting a control signal to denote a continuous region when the first resonance peak is detected,
 - 5 c. de-asserting the control signal and jumping to the next continuous tuning region when the next resonance peak is found within this continuous tuning region, and
 - d. repeating the above steps (b-c) until a
 - 10 sufficient range of wavelength has been swept.

6. The method as claimed in any preceding claim wherein the regions of continuing tuning operation of the laser are defined by:

- 15 calibrating the laser so as to provide a range of currents with no mode jumps,
- selecting continuous regions with a first frequency overlap that have a resonance peak in the wavelength response from their beginnings and
- 20 ends, and
- setting the currents whilst sweeping through those wavelengths so as to provide a smoothly transitioning wavelength sweep.

25 7. The method as claimed in claim 6 wherein the step of setting the currents is provided by one or more of the following:

- filtering,
- 30 shaping.

8. The method as claimed in any preceding claim further comprising the step of assigning a frequency (F_{meas}) or wavelength (λ_{meas}) value to discrete points within the continuous region of operation of the laser device, the

35 value being assigned by:

measuring the time from the resonance peak at the beginning of the sweep to the measurement instant (T_{meas}),

measuring the time required to sweep between

5 adjacent resonance peaks ($T_{segment}$), and

calculating the value by extracting a value for T_{meas} from $T_{segment}$

9. The method as claimed in claim 8 wherein the value
10 is a frequency value (F_{meas}) and the wavelength reference is an etalon, the frequency being calculated using the equation:

$$F_{meas} = FSR_{Etalon} * \frac{T_{meas}}{T_{segment}} + F_{SegmentStart}$$

where FSR_{Etalon} is the free spectral range of the
15 reference etalon and $F_{SegmentStart}$ is the absolute frequency of the first resonant etalon peak in the segment.

10. The method as claimed in any preceding claim further
20 including the step of using the laser device as a reference source for a second device

11. The method as claimed in any preceding claim further
25 comprising the step of using the regions of continuous tuning operation to define the spectral characteristics of a second laser device.

30 12. The method as claimed in any one of claims 1 to 10 further comprising the step of using the regions of continuous tuning operation to provide an optical spectrum analyser.

13. The method as claimed in any preceding claim wherein the wavelength reference is provided by one or more of the following:

a fabry perot etalon,
a gas cell,
fibre bragg grating,
notch filter,
a reflective fabry perot etalon, and
optical filter.

14. The method as claimed in any preceding claim wherein any portion of the resonance peak is used to determine the location of the resonance peak.

15. A optical arrangement adapted to provide a set of continuous tuning regions from a discontinuously tuned laser, the arrangement comprising:

a wavelength reference having at least first and second resonance peaks associated therewith,

a tunable laser,

means for sweeping the laser across a pre-determined wavelength range of the wavelength reference, and

means for defining, within the laser sweep, one or more regions of continuous tuning operation of the laser, each of the regions corresponding to a response of the laser between adjacent resonance peaks of the wavelength reference.

16. A method substantially as hereinbefore described with reference to and/or as illustrated in Figures 1 to 8 of the accompanying drawings.

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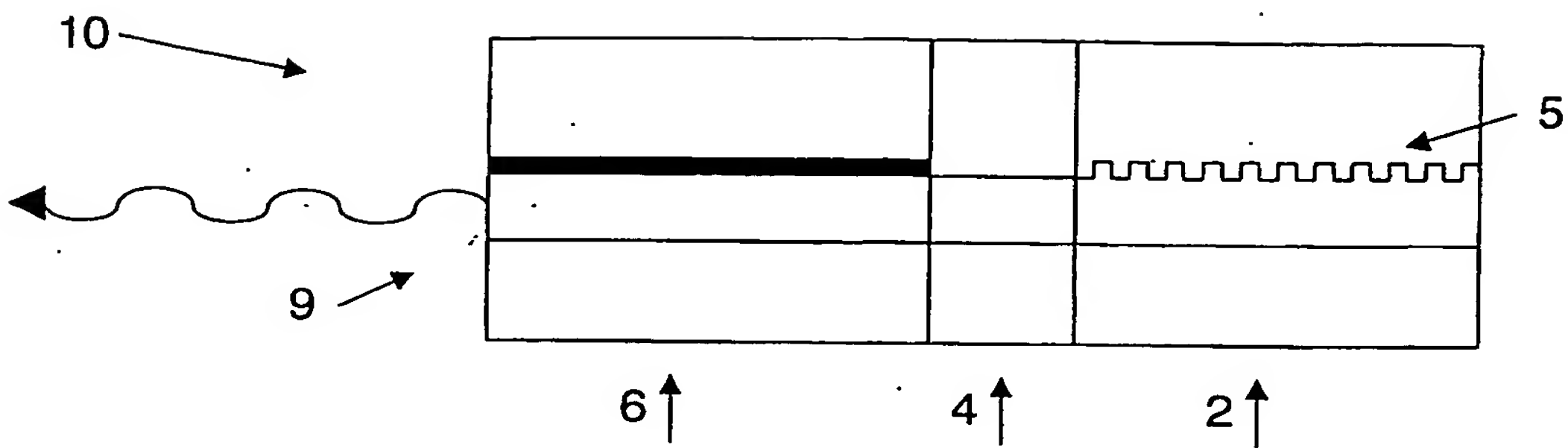


Figure 1

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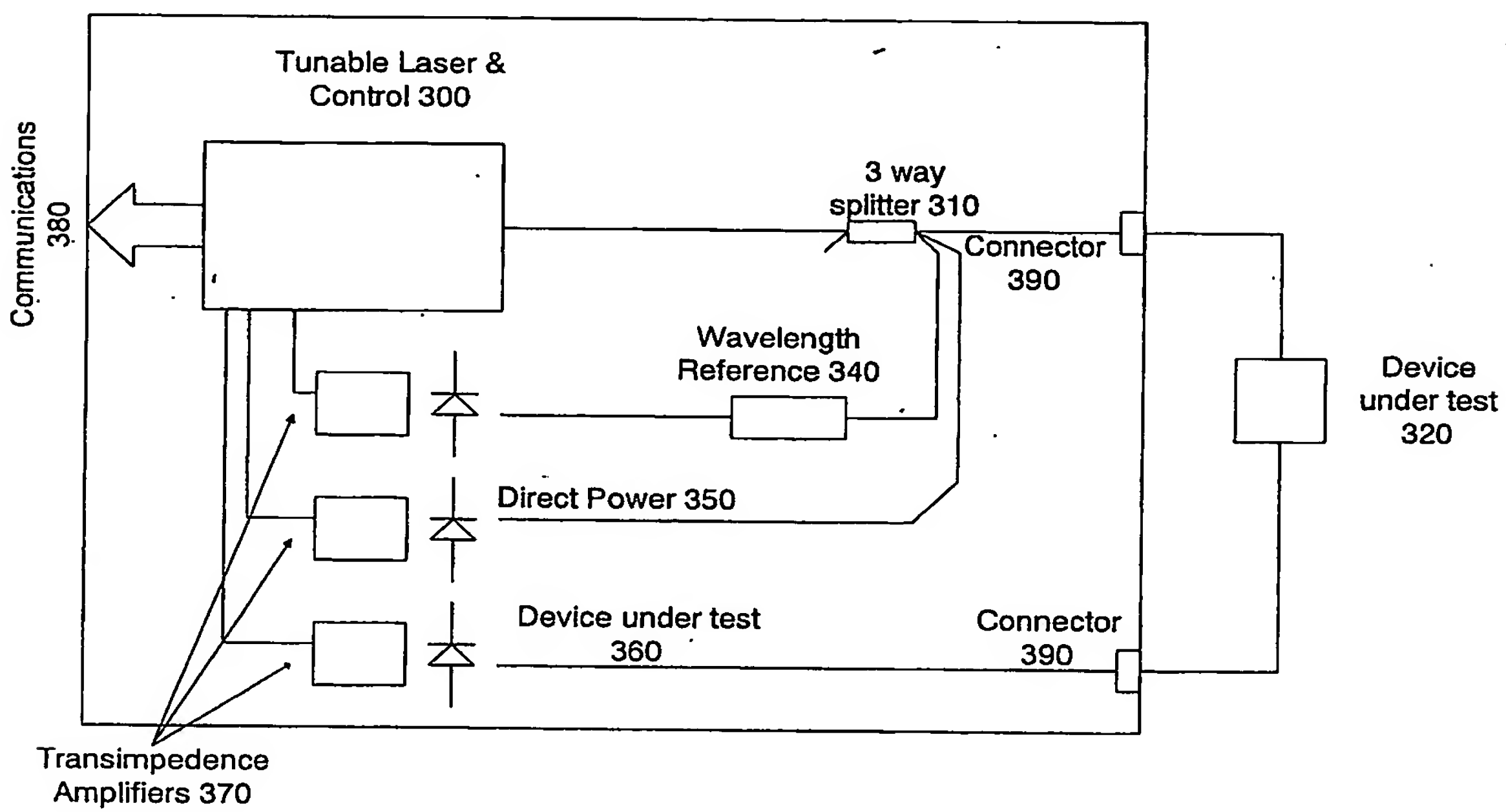


Figure 2

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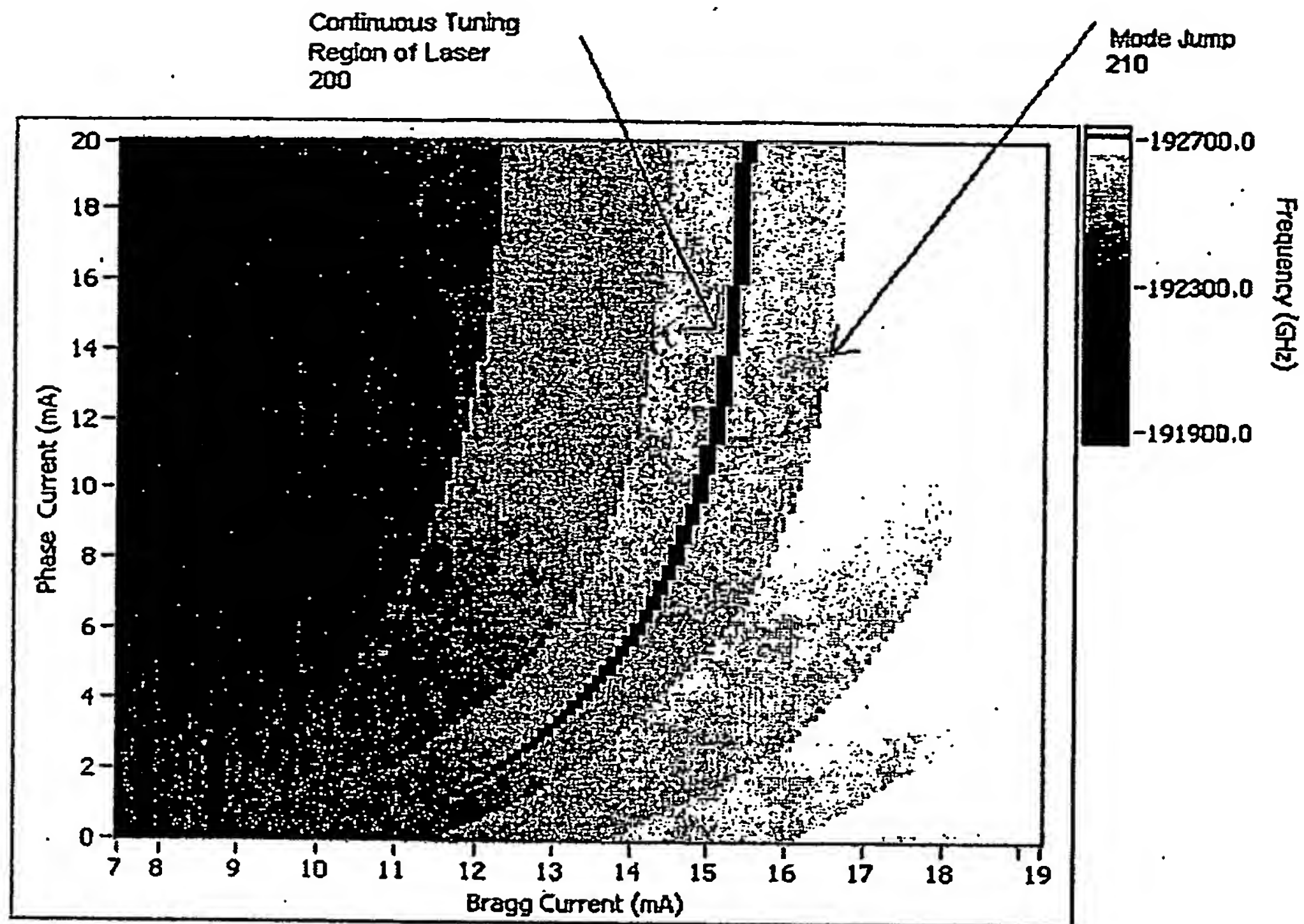
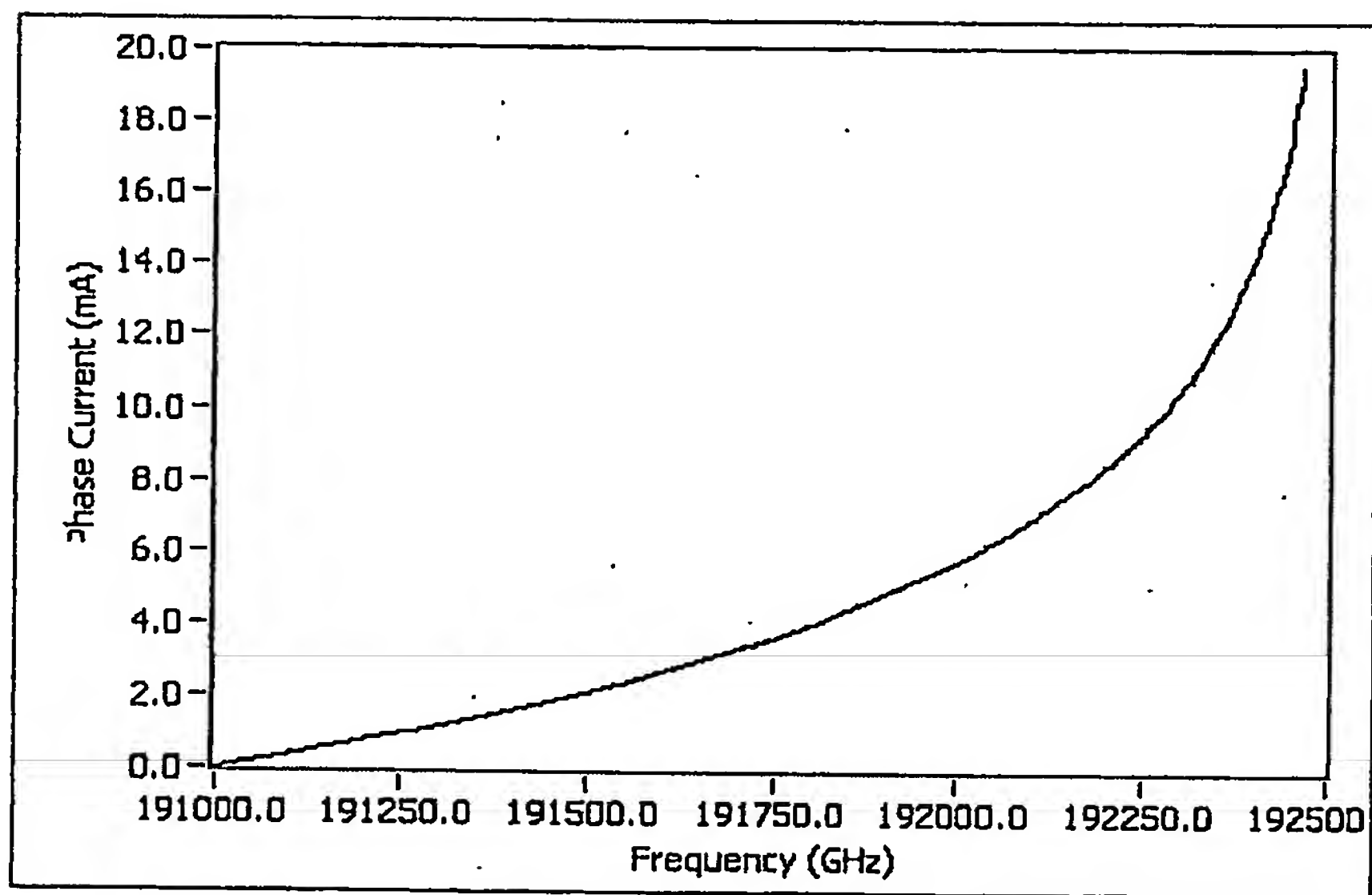


Figure 3



5 Figure 4

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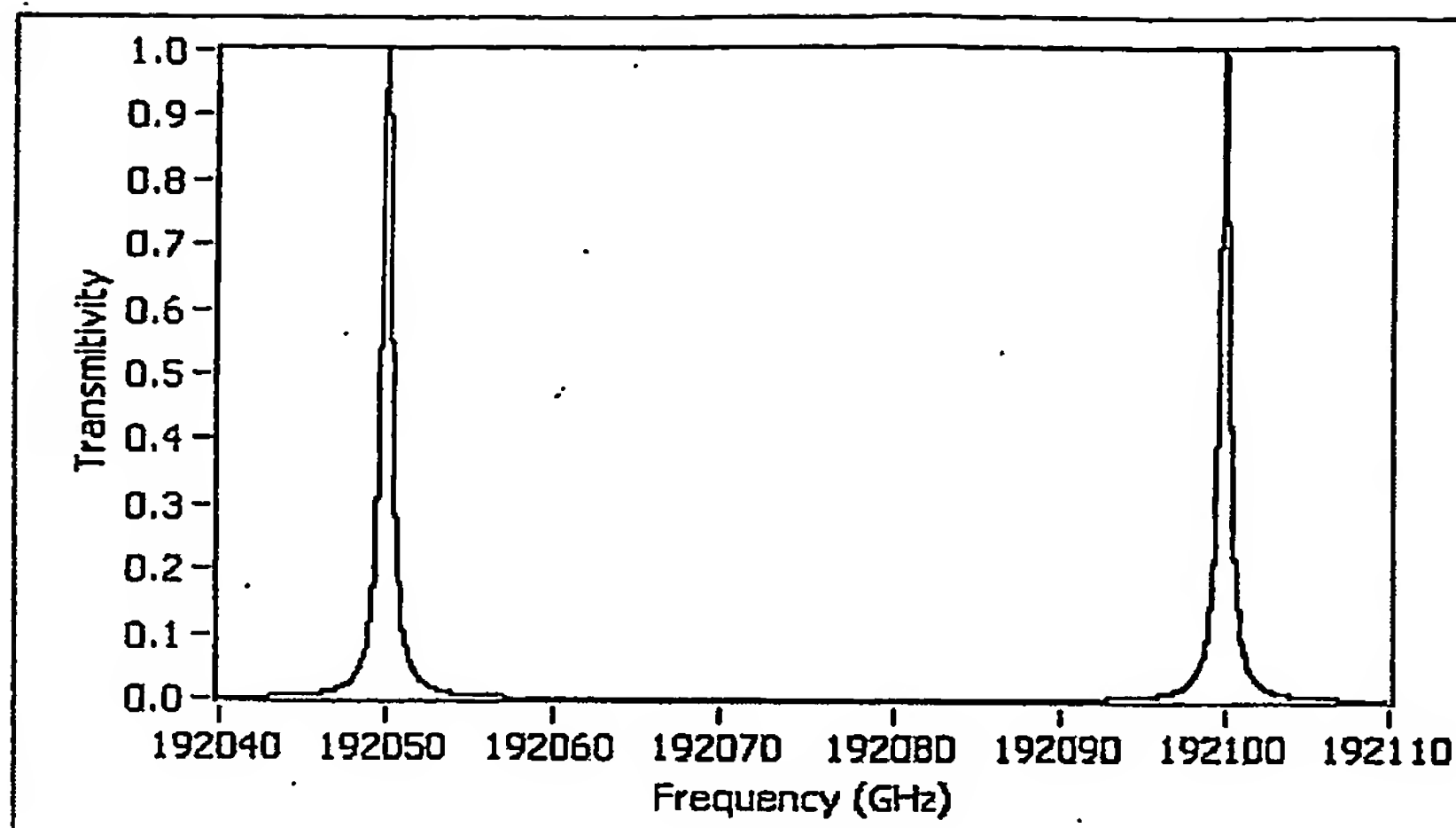
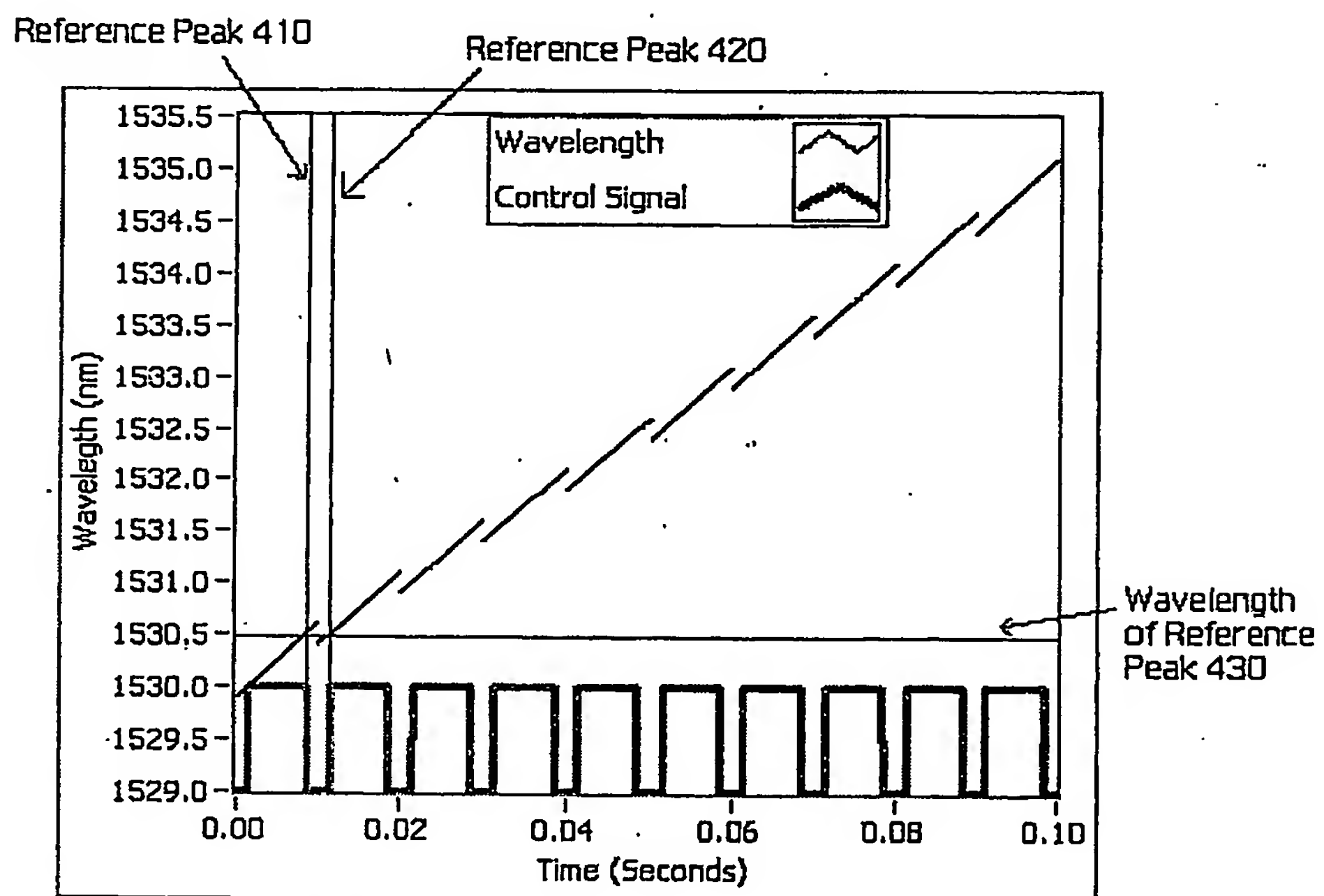


Figure 5



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Figure 6

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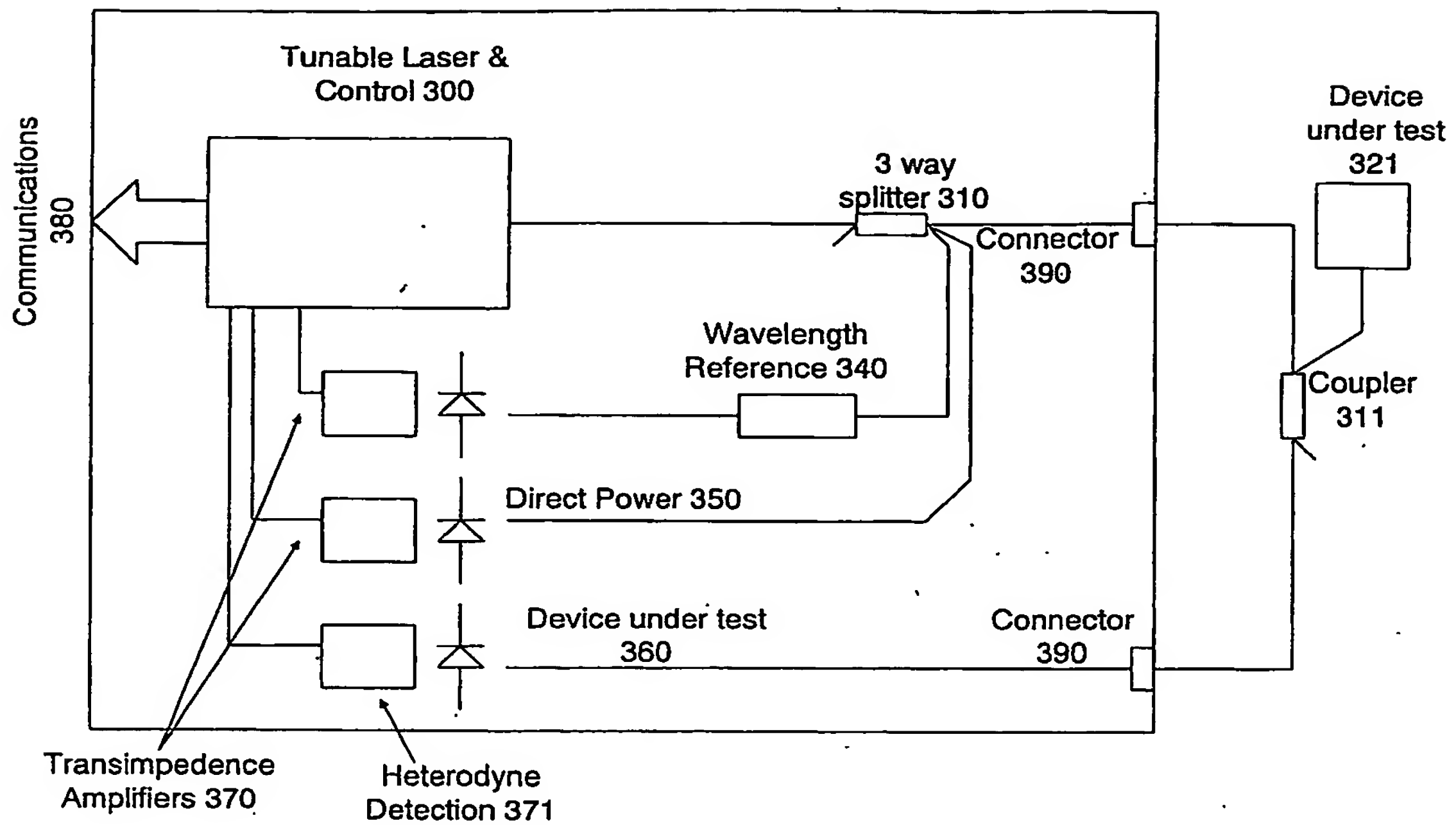


Figure 7